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FACILITIES AVAILABILITY AND REQUIREMENTS FOR FABRICATION OF CASE SEGMENTS AND CLOSURES FOR LARGE SOLID PROPELLANT ROCKET MOTORS

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ABSTRACT

This report has been prepared to determine current industry capability for fabricating case segments and closures for large segmented solid propellant rocket motors. The study was based on the premise that large solid rocket motor cases with maximum reliability would be required as early as possible. Therefore, the basic large motor development program philosophy to utilize only current state of the art materials and manufacturing processes has been followed.

The capability of industry to fabricate cylindrical case segments using roll and weld technique, machined ring forging and power shear spinning is presented.

For closure fabrication, the capability of industry to fabricate closures by spinning, explosive forming and welding is presented. Because of the limited technology currently available with more advanced fabrication techniques such as strip lap, fiberglas winding and cryogenic stretch forming, these processes could not be considered for immediate use on a large motor development program.

The current capabilities of industry are further broken down to cover available vertical lathes, horizontal lathes, heat treat facilities, expandable mandrels, forged ring facilities, power shear spinning, welding, roll formers and flat plate production. Production schedules were developed to predict the required number of case segments for several motor diameters under consideration. Tables are presented which summarize the availability and requirements of facilities, cost and lead time to obtain the capability for four motor diameters; 100, 136, 156 and 200 inches diameter.

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INTRODUCTION

The necessity has been established to determine the capabilities of industry to fabricate large rocket motor cases and closures for peak research and development testing. The selection of a fabrication technique is dependent on the reliability of the chosen technique and the availability of the required facilities or the capability of installing such facilities in a timely manner. Therefore, an attempt was made to evaluate the capability of industry to fabricate rocket motor segments and closures by various known methods. The collection of information contained herein represents a summary of facts obtained during a two month period by a telephone survey and several trips conducted in August and September 1961. Representatives were contacted from various rocket, manufacturing, machine and transportation companies throughout the United States. Certainly, no such study could be all inclusive nor 100 percent accurate because of the inadequacy of verbal communication. It is felt, however, that this report provides a representative cross section of industry today and the conclusions drawn are considered to be valid.

DISCUSSION

In order to make a study such as this more meaningful, a development program was laid out to investigate the capability of fabricating rocket motor cases of several diameters. The diameters selected were 100 inches, 136 inches, 156 inches and 200 inches since these sizes are representative of the diameters currently being considered for future large motor development programs. It was necessary to estimate the number of case segments required per month during the development program. It is assumed these production rates are representative of an accelerated single contractor effort. If a dual contractor effort is considered, the facilities requirements must be doubled to reflect this increased production rate.

The following table summarizes the number of segments per month needed for various phases of the program.

			Total Segments/Month		
Mtr. Dia. (Inches)	No. Center Seg. /Mtr.	Gross Prop. Wt.	R and D Testing	Qual. Testing	PFRT Testing
100	5	330,000	4	4	7
136	6	855,000	8	12	18
156	7	1,250,000	7	13	16
200	6	1,878,000	5	9	15

The report is in two parts. Part I includes fabrication of rocket motor cylindrical case segments and Part II covers rocket motor closure fabrication.

PART I

FABRICATION OF ROCKET MOTOR CYLINDRICAL CASE SEGMENTS

FABRICATING TECHNIQUES CONSIDERED.

Roll and Weld Technique.

This method of fabrication is widely used throughout industry in fabricating rocket motor cases. Only slight modifications are required to adapt this method to segmented case fabrication. Flat steel plates are rolled to form cylinders and then welded longitudinally. Upsetting the ends to provide reinforced sections for welding may be desirable, but is not considered necessary at the present time. Two or more of these rolled sections can be welded together circumferentially to produce cylindrical sections of the desired length. For the rocket motor segments under consideration, it is necessary to weld a full diameter forged joint ring on each end of the cylindrical segments for subsequent mating of the chamber assemblies. Close control of welding operations can produce diametral tolerances on these cylindrical sections approaching 0.1% of nominal case diameter. Since this represents approximately 0.15 inches on a 156 inch diameter case segment, this may not be desirable. In either case, an internal sizing operation on a stretch press (expandable mandrel) is desirable to obtain the exact internal case diameter after welding. This operation also removes any localized stresses at the weld areas due to mismatch and produces a more uniform material cross section by actually yielding all parts of the case material.

After sizing, the case segment is supported internally to minimize effects of distortion and the entire assembly is heat treated to obtain the desired strength level in the case material. Sand blasting removes any scale formed during the heat treat cycle. The final operation is to finish machine the joint rings on each end of the segment to the required configuration. No machining is required on the rolled center section between the joint rings.

Machined Ring Forging Technique.

This technique offers a method of manufacturing case segments which eliminates the longitudinal weld requirement dictated by the roll and weld technique. The less critical (from a stress standpoint) circumferential welds are still required. A case segment is fabricated by welding together (circumferentially) large diameter rolled ring forgings to form the desired segment length. The maximum length of rolled ring forgings presently available is 65 inches, therefore, three to four rolled ring forgings would be required for the case segment lengths under consideration. Case segments can be fabricated from these rolled ring forgings by two divergent approaches: one approach requires heat treat of the entire case segment assembly after welding and the other approach does not require heat treatment of the case segment assembly after welding. The relative merits of each approach are discussed below.

Heat Treat After Assembly.

Rolled ring forgings are received in the "as rolled," or annealed condition. As such, they have large amounts of slag which must be removed by machining. These individual ring forgings can be finish machined to produce the required wall thickness prior to welding the individual ring forgings together. However, the ends of each ring forging must have a slightly increased section thickness to allow for satisfactory welding. Also, provisions must be made to incorporate increased sections at the end of each case segment assembly to allow machining of the segment joint configuration. By proper fixturing, the individual machined forgings can now be joined together with circumferential welding. After stress relieving, a normal heat treat cycle is required to obtain the desired strength level in the assembled case segment material. Finally, the finished joint configuration can be machined on each end of the case segment assembly.

This method of fabrication is currently being used for production of Minuteman cases and is well established. On very large diameter cases, this technique may become extremely costly and thereby lessen the attractiveness of increased reliability. It is estimated that a minimum weight of steel forgings equal to twice the finished case segment weight would be required. This is necessary to allow for forged ring rolling tolerances, scale removal and increased sections at the weld area. Thus, for a typical case segment weight of 15,000 pounds, an additional 15,000 pounds of steel would have to be procured at an estimated cost of $1.00 per pound. For the large number of case segments being considered, the total difference in material cost would become appreciable. In addition, much more machining time is required to bring the rough forgings to the required dimensions.

Heat Treat Prior to Assembly.

Rolled ring forgings are received in the heat treated and hardened condition. The only advantage to this approach is that a large atmospherically controlled heat treat furnace is not required. The rolled ring forgings can be heat treated in any available gas fired furnace. The large amount of carburized surface material can then be machined away from the ring forging, thus exposing acceptable hardened steel for case segment fabrication. Then, in a manner similar to that followed in the previous approach, the individual ring forgings are then finish machined to produce the required wall thickness and then welded together circumferentially. However, since the final assembly is not heat treated after assembly, the end of each ring forging must have a greatly increased section thickness (at least twice the minimum wall thickness) to allow for localized loss of yield strength during the welding operation. This method is even more undesirable from an economic standpoint than the approach previously outlined. It has been conservatively calculated that this approach would require a minimum weight of ring forgings equal to four times the finished case weight. This is due to the large amount of excess material required to allow for surface carburizing during heat treat and the greatly increased section thickness required to compensate for localized loss of yield strength at each non-heat treated weld area. Furthermore, the requirement to machine increased quantities of fully hardened steel forgings would make the machining time and cost impractical if not prohibitive. It is estimated that the time and material savings from a single 156 inch diameter motor would be sufficient to design, and build an atmospherically controlled heat treat furnace. Therefore, this approach has not been considered further in this report.

Power Shear Spinning Technique.

This method of fabrication is being used more frequently as the state of the art advances. A ring forging or roll and weld preform with a wall thickness greater than the desired case wall thickness is placed over one end of a mandrel sized to the internal dimensions of the case segment. Large rollers then force the preform material to "cold flow" by shearing along the length of the mandrel as the mandrel and forging are caused to spin about their longitudinal axis. This operation requires tremendous force to shear the metal at ambient temperature. Several passes are required to reduce the original preform to the desired wall thickness and concurrently, increase the preform to the desired length. The possibility exists to roll thicker sections on either end suitable for machining joints, however, this process appears to be very costly because a collapsible mandrel is required. After rolling is completed, the metal has been cold worked tremendously and has uneven stress distribution. Therefore, full heat treating is required similar to the roll and weld technique. After the heat treat cycle, the ends are then machined to the desired joint configuration. The main advantage is that the longitudinal weld is eliminated thus permitting use of a higher design stress level for a given material with no loss of reliability. The cost for fabricating cases is relatively independent of the stress level of the end product. Thus, this process becomes more attractive when it is necessary to employ high yield strength material. The main disadvantage is that it is unproven in the large sizes and that the initial tooling required is rather expensive. However, the tooling should be reusable indefinitely with adequate care during use, and thus it appears for fabricating a large number of cases this method would become attractive from a cost standpoint. The largest diameter case fabricated to date by this technique has been 65 inches even though 120 inches diameter is the maximum capacity of the facility. It is estimated that the cost of fabricating case segments by this method (exclusive of facilities) would be twice the cost for roll and weld fabrication. This method is not presently attractive for early production of large case segments due to the lack of suitable facilities and demonstrated capability. A more detailed discussion of the facilities has been included later.

AVAILABLE FACILITIES.

In an attempt to evaluate industry's capability to fabricate large solid propellant rocket motor cases, a telephone survey was conducted by which some sixty-five companies were contacted. (See Appendix III for a complete listing). The existing capabilities are categorized below. The capability of industry to meet the requirements for fabricating case segments by the three selected methods is discussed.

Roll and Weld Technique.

There are several steel companies that are capable of producing Ladish D6aC steel billets: Crucible Steel Co of America, Pittsburg, Pa.; Republic Steel Co., Cleveland, Ohio; Alleghany Ludlum Co., Pittsburg, Pa.; and Midvale - Heppenstale Steel Co., Pittsburg, Pa. The average minimum production rate for each of these companies is rated at one 50,000 pound billet per day. This would be sufficient to meet any of the schedule presented. Likewise, the availability of vacuum remelted AMS 6434 or AMS 255 is considered adequate to meet any of the production schedules outlined.

The major producer of flat plate steel with Ladish I 6aC steel is Lukins Steel Co., Coatsville, Pa. Their present capability of producing one-half inch thick steel plate of Ladish D6aC is:

Width	Length
140 inches	520 inches
150 inches	480 inches
160 inches	400 inches
170 inches	360 inches
186 inches	300 inches

The limiting factor in producing larger sizes of flat plate is their rolling mill. The Ladish D6aC cold works to the point that a heavier mill would be required to roll larger sizes. The lead time for a new mill is estimated at two years. It would be easier to heat treat the semi-finished plate steel and then re-roll it. Two plates could be welded and then rolled. A lead time of seven to eight weeks is required for delivery and they are capable of producing twenty-four plates per week.

Rolling flat plate sections up to twenty feet wide appears to be feasible with existing equipment. Practically every major steel facility has the capability of rolling steel plate into cylindrical segments 12 feet to 17 feet diameter and 12 feet to 20 feet long.

Two facilities that were contacted had the capability of forging joint rings larger than 14 feet in diameter. U. S. Steel stated they could produce 17 feet diameter ring forgings at a rate of one per week. The Ladish Steel Co., stated they could produce up to 17 feet diameter ring forgings at a rate of four per day with their present rolling equipment. This is in excess of the maximum that would be required for any of the programs presented.

By examining Appendix III, it can be seen that several companies have the capability of automatic welding large diameter steel sections using inert gas. Most of these companies have the capability to hold the tolerances required with existing facilities. However, each facility would require approximately $150,000 for special tooling to adapt to any of the various size diameters being considered. This additional equipment needed such as heater holders, rings and positioners would be classified as special equipment or tooling and not be included in this report.

The largest expandable mandrel available in this country is located in Inglewood, Calif., at the Arrow-Smith Tool and Die Co. The present facility is capable of stretching a 12 feet long 13 feet diameter steel case. The Hufford Machine Works, El Segundo, Calif., has a machine which can stretch up to 10 feet in diameter, 23 feet long. Douglas Aircraft has a 6 feet maximum diameter, 30 feet long expandable mandrel which is used in Nike-Zeus cases. The Douglas Facility could be modified to take 20 feet diameter in three months for $50,000. A new machine could be built in three months by Arrow-Smith Tool and Die Co., to the same size for $150,000. Since the Douglas facility is being used for Nike-Zeus cases, it is considered advisable to build a new facility.

The following observations have been made regarding atmospherically controlled heat treat facilities: Three types of currently available heat treat facilities are considered satisfactory for treatment of the rocket motor case; the gantry furnace, the pit furnace and a modified car-bottom furnace with provisions for vertical suspension of the case segment.

The atmospherically controlled gantry furnace is the most expensive, but is rated as the best approach since it produces the most uniform stress distribution along the case length. The case segment is bottom quenched, and thus is never exposed to the atmosphere until after the quench operation. The pit type furnace is the least expensive, but does not produce uniform longitudinal stress distribution. The case segment must be lifted out of the heat treat pit and inserted into the quench media. Thus, the top of the case is the first section to be exposed to air and the last section being quenched. The modified car-bottom furnace is considered acceptable if provisions are included to provide vertical suspension of cases during heat treat. Further, a protective retort or bottom quench method must be provided to minimize effects of the atmosphere prior to quench.

J. W. Rex, Landsdale, Pa., is presently installing a large controlled atmosphere gantry furnace and quench facility which will be operational in November 1961. The working diameter is 140 inches, and the working length is 35 feet. An oil quench is available, but salt quench will require tank modification. J. W. Rex Co. has recently announced that they would modify the above facility to accept 160 inches diameter segments if a $500,000 order were assured or the modification cost of $150,000 were provided. This modification would require only 90 days and would include oil quench provisions. Additional modification would be required for salt quench.

The Thurner Co., Milwaukee, Wis., is presently negotiating to build a 100 inch diameter gantry furnace with atmospheric control. This firm was not aware that a need existed for a diameter larger than 100 inches. The present design could easily be modified to 200 inches in diameter. This firm indicated an interest in modifying the present design and building to the larger size.

United Heat Treat Co., Fort Worth, Texas., has a slot and car furnace with atmospheric control. The size of this furnace is 16 feet high, 14 feet wide and 8 feet long. This company is willing to lengthen the furnace to any required length by 1 January 1962 if there is any justification.

Consolidated Western is presently modifying their existing stress relieve furnace to incorporate atmospheric control, vertical case suspension, and quench media for all motor sizes being considered. The furnace is an 18' x 18' x 61' long car bottom furnace and will be capable of 2100^{o}F. This This is planned to be operational by January 1962.

Willamette Iron and Steel Co., Portland, Ore., has plans to build a 15 feet diameter by 20 feet deep gantry furnace with atmospheric control and quench facilities. This will be built with company funds and can be operational within 120 days after initiation of work. Likewise, this installation is dependent upon a firm commitment to heat treat several motor cases.

Two other companies are willing to modify their existing facilities (company funded) to meet Air Force requirements upon firm commitment that a need exists for such a facility. They are: Hydraulic Press Manufacturing Co., Mount Gilead, Ohio., and Cal Doran Co., Los Angeles, Calif.

General Electric, Cincinatti., presently has an operational Gantry Furnace capable of 120 inches in diameter and is atmospherically controlled. Quenching Tanks are available. Aerojet General currently has a 100 inches diameter Gantry Furnace with atmospheric control.

Table 1 lists all the large vertical lathes that were located and the specifications of each machine. This list is probably not complete, but certainly represents a very large portion of what is available throughout the country. Approximately 100 companies were contacted but only those companies that have mills of the size larger than 12 feet in diameter were listed. The ready availability and low utilization of vertical lathes suitable for use without modification makes this method of machining case segments most attractive at present. The limiting factor in this case was found to be the vertical clearance on these machines. This could impose length restrictions of

TABLE 1

VERTICAL LATHES

Company	Maximum Diameter (Feet)	Vertical Clearance (Feet)	Tolerance On Diameter	Remarks
A. O. Smith Co. Milwaukee, Wis.	20	16 ft	±.005	
Vernon All Steel Co.	20	12	±.002	New, will not modify
Nordberg, Corp. St. Louis, Mo.	20	12	±.005	
Giddings and Lewis Fond Du Lac, Wis.	20	12	±.002	
C. H. Wheller Co.	19	12	±.003	
	24	12	±.003	
Blaw Knox E. Chicago, Ind.	24	14	±.002	
Manitowoc Engr. Co. Manitowoc, Wis.	25	15	±.005	
John Mohr and Sons Chicago, Ill.	26	9 1/4	±.008	Impractical to modify
Cal Mach El Monte, Calif.	27	25	±.005	Operational Nov 61
Allis Chalmers Co. Milwaukee, Wis.	16	18	±.005	
	16	18	"	
	28	15	"	
	30	18	"	
	40	18	"	
Threadwell Const. Co. Midland, Pa.	30	12	±.0001	For Sale
Baldwin-Lima-Hamilton Corp. Eddystone Division Philadelphia, Pa.	35	20	±.008	A builder of VTL's
	40	16	±.008	

TABLE 1 (CONT.)

Company	Maximum Diameter (Feet)	Vertical Clearance (Feet)	Tolerance On Diameter	Remarks
Newport News Shipbhilding Newport News, Va.	42 16	25-1/2 16.9	±.005 ±.005	
Conelsville Mfg. Co. Connelsville, Pa.	16	5 ft. 10 in.	±.010	
Consolidated Western	16	8	±.002	$100,000 estimated to modify VTL to obtain 14 feet vertical clearance.
Leo Kinco Co. Montebello, Calif.	12	12	±.010	
Nat'l Steel Supply Los Angeles, Calif.	14	7	±.000-1/2	
Manitowoc Engr. Corp. Manitowoc, Wis.	14	10	±.005	
Blaw Knox E. Chicago, Ind.	12	10	±.002	
Consolidated Western Steel Maywood, Calif.	12	7	±.002	
Hufford Mach. Works El Segundo, Calif.	12	7.2		
Nordberg Corp. St. Louis, Mo.	12	7		
Wm. B. Pollick Co. Youngstown, Ohio	22	11	±.005	Interested in Modification
Westinghouse Corp.	16.67	25	±.005	Being Utilized
Naval Ship Yard Seattle, Wash.	22 14 12	7 7 7	±.005 " "	Can modify at reasonable cost to obtain vert. clearance
Naval Gun Factory	12 14 17	14 11 3	-- -- --	Surplus machines

TABLE 1 (CONT.)

Company	Maximum Diameter (Feet)	Vertical Clearance (Feet)	Tolerance On Diameter	Remarks
Stearns Rogers Co. Denver, Colo.	16 ft. 13 ft.	11 ft. 6 in. 12 ft. 4 in.	±.005 ±.005	
Portland Industrial Co. Portland, Maine	12 16' 16 24 23	10 9-1/2 9-1/2 9 10		Can modify with blocks to obtain vertical clearance
Bethlehem Steel Co. Bethlehem, Pa.	25	13 ft. 4 in.	±.005	
Babcok and Wilcox Barbeton, Ohio	16	18	±.005	
Erie Forge and Steel Erie, Pa.	15 25	10 12	±.005 "	New; ready by 1 Nov 61
Excelco Developments, Inc. Silver Creek, N.Y.	10' 10' 13'-4"	13 13 16-18		Currently being installed. Increased vertical clearance with blocks.
General Electric Co. Evendale, Ohio and Schenectady, N.Y.	16' 24' 20'	14 14 Unknown		

approximately 16 feet for the segment length if the motor production rate exceeds the machining capacity of the mills available with 16 feet vertical clearance or larger. However, the number of machines available is considered adequate to handle maximum production requirements through qualification test (except for 200 inches diameter) if the segment length is limited to approximately 16 feet.

Construction of new larger size vertical lathes is possible, but would require 18 months per machine and cost approximately one million dollars each. Since only a few companies are capable of manufacturing these machines, only a limited number of new machines could be realized in the next several years. Therefore, it is considered advisable to use existing machines rather than relying upon the construction of new machines at the present time.

Only a very limited number of horizontal engine lathes are currently available that could accept large diameter motor cases without extensive modification. The main disadvantage of the horizontal engine lathe would be the large amount of special tooling and operations required to prevent the case segment from "sagging" in the middle during machining operations. This would not be required for machining operations in the vertical position. The main advantage offered from use of horizontal engine lathes is the longer bed length generally available which will eliminate restrictions on segment length imposed by vertical lathes. However, for an extremely large development program (dual contractor effort) with large production rates, the number of horizontal lathes that could even be considered for modification appears marginal since only four of the companies contacted had such machines.

Two large machining companies, the Excelco Development Inc., and Kaiser Fleetwing, Inc., have indicated that they would each modify two existing engine lathes to accept up to 160 inches diameter swing. These modifications would take approximately five months and ROM costs are approximately $100,000 for each installation.

Machined Ring Forging Technique.

Even though this fabrication technique would require more than twice the quantity of steel to produce the same number of finished motor segments, the steel billet production capacity quoted previously is still considered to be adequate for either D6aC or AMS 6434 material.

Due to the relatively small amount of flat plate required for this method of fabrication, no problem will be encountered.

The Ladish Steel Co., Cudahy, Wis., has a ring roller facility presently in operation that is capable of rolling the forged cylinders to diameters greater than 200 inches. Their maximum production rate would be approximately four large forgings per day which would require nearly the total billet output of one 50,000 pound billet per day from each of the steel companies mentioned previously (D6aC only).

Even though this technique requires much more machining than the roll and weld process, the large machine requirements for the finished segments can be considered to be the same as with roll and weld. This assumes that most of rough machining on the shorter length forgings could be performed on the large number of machines available with smaller vertical clearance (See Table 1) and thus not tie up the more critical large machines. This approach could be much more inefficient if the required machines were separated geographically, and tends to complicate and raise the expense for this method of fabrication.

The expandable mandrel facility would not be required for this method of fabrication.

The composite ring forging method of fabrication has requirements for heat treat and welding similar to that required for the roll and weld technique. The discussion of available facilities for these items is therefore applicable.

Power Shear Spinning Technique.

The largest rocket motor cases fabricated by the power shear spinning process is the first stage Minuteman, 65 inches diameter and 120 inches long.

The largest spinning facility presently available is capable of forming case segments up to 120 inches diameter and 300 inches long if the "back-spinning" process is used. Since shear forming has not been demonstrated for the larger diameters being considered, this method of fabrication cannot be considered for large case segment fabrication at the present time.

The above mentioned facility is located at the Hufford Machine Works Inc., El Segundo, Calif. They are currently designing and plan to build a similar facility capable of producing 175 or 200 inch diameter segments up to 300 inch long as well as closures of the same diameters. The estimated cost for this facility will be two and one-half to three million dollars. This unit cannot be operational in less than 18 months.

The Curtis Wright Corp. is also spinning Minuteman cases and estimate facilities could be built to produce 17 feet diameters for $400,000. In view of Hufford's estimate of two and one-half to three million dollars for a similar facility, it is not believed that the C. W. estimate is accurate.

When considering the spinning technique, the foregoing discussions on the available facilities for the roll and weld fabrication technique are applicable for heat treat facilities, machining capability, ring forging production (for joint rings), expandable mandrels, and welding. In addition, similar quantities of large ring forgings, as discussed under the composite ring forging technique, would be required for the spinning blanks.

TRANSPORTATION.

The 100 inch and 136 inch diameter case segments can be handled easily by all forms of available transportation including truck, train and air (C-133 only).

The 156 inch diameter case segments can only be moved by special routing on truck or train. Truck movement is not practical for long distances because of traffic and routing problems, however, short hauls in conjunction with train movement is considered practical as well as necessary. The maximum envelope permissible in continental United States for rail shipment is

14 feet wide by 17-1/2 feet high. This requires special routing and special drop center flat cars. The maximum weight limitation is 500,000 pounds.

The 200 inch motor segment dimensions exceed the maximum allowable dimensions that may be shipped in the United States by truck, train or air. Thus, all long distance movement of segments would have to be done by water transportation. This eliminates several manufacturing companies from consideration because they are not located on navigable waters.

FACILITIES REQUIREMENT SUMMARY.

Tables 2 through 5 of this report summarize the facility requirements for fabricating rocket motor case segments of 100 inch, 136 inch, 156 inch and 200 inch diameters. A discussion of the critical or prime items for each size is included.

Roll and Weld Technique.

As can be seen in Tables 2 and 3, the 100 inch and 136 inch diameter sizes require only the expandable mandrel facility. There are four companies that indicate an interest in fabricating such a facility; Arrow-Smith Tool and Die Co., Inglewood, Calif., Grotness Machine Works, Chicago, Ill., Hufford Machine Works, El Segundo, Calif., and Vernon All Steel Co., Chicago, Ill. The shortest estimated lead time is three months by Arrow-Smith and the longest is 12 months by Grotness Machine Works (see appendix for discussion). Conservative estimates are that a complete facility can be installed within three to four months for $150,000.

156 inch diameter: The maximum number of vertical boring mills required during this program would be twelve. It is known that at least fourteen are available with vertical clearance greater than 14 feet in addition to a few horizontal engine lathes with the required capacity. It is assumed that Consolidated Western Steel Co., will have a satisfactory heat treat furnace operational before this item becomes critical. If this does not materialize, any of several companies will build or modify a suitable facility within six months with their own funds. This is based upon firm commitment for future orders. (The best estimated cost for a new facility is $600,000 to

$700,000). Similarly, a suitable stretch press facility (expandable mandrel) can be installed in three to four months for $150,000.

200 inches diameter: Several problems arise with the 200 inch diameter. The survey conducted revealed only nine vertical boring mills with a vertical clearance of 14 feet or greater located near navigable waters. In addition, one horizontal lathe was found with adequate clearance. It is not considered advisable to modify existing inadequate lathes when considering diameters of this size. It is estimated that 23 machines at 80% utilization would be required to meet peak motor production schedules during PFRT. Construction of the additional machines could be done at approximately $1,000,000 each, but the lead time would be nearly 18 months. Since only three companies, Bullard Co., of Bridgeport, Conn., Baldwin -Lima-Hamilton of Eddystone, Pa., and Gidding and Lewis of Fon Du Lac, Wis., are actively engaged in manufacturing such machines, limited production rates may have to be considered until suitable facilities can be obtained near navigable waterways.

A heat treat facility would likewise be required for the 200 inch diameter motor program. The minimum cost for such a facility would be approximately $1,000,000 and would require six to eight months for installation. The Consolidated Western furnace would be large enough, but transportation problems would limit the practicability of such a setup. It would be more desirable to have the heat treat facility close to the machining facilities, most of which are located on the East Coast.

A suitable stretch press facility can be installed at any desirable location within six months for $300,000 to $500,000. Other required facilities are considered adequate but serious consideration should be given to consolidation of all required facilities into a centralized location close to navigable water. Use of existing facilities does not appear practical for efficient fabrication of 200 inch diameter motors.

<u>Machined Ring Forging Technique.</u>

Case Segments 100 and 136 Inch Diameter: See Tables 2 and 3. No additional facilities would be required to meet the minimum requirements for production as developed herein. However, a fixed amount of special tooling would be required to adapt existing welding facilities to any specific diameter selected.

Case Segment 156 Inch Diameter: See Table 4. The only facility required would be the heat treat facility estimated previously at $700,000.

Case Segments 200 inch Diameter: See Table 5. With the exception of an expandable mandrel facility, the foregoing discussion on the 200 inch diameter for the roll and weld technique is applicable to this Composite Ring Forging Technique. This size does not appear practical with present industrial capabilities.

TABLE 2

ROCKET MOTOR CASE FABRICATION
FACILITIES REQUIREMENTS FOR 100 INCHES DIAMETER

FACILITIES	NO. AVAILABLE	ADDITIONAL REQ'D	FACILITY COST	LEAD TIME
VERTICAL LATHES	16	0	0	--
HEAT TREAT FACILITIES	ADEQUATE	0	0	--
EXPANDABLE MANDRELS	0	1	150,000	6 MO.
FORGED RING FACILITIES	ADEQUATE	0	0	--
ROLL FORMERS	ADEQUATE	0	0	--
WELDING	ADEQUATE*	0	0	--
FLAT PLATE PRODUCTION	ADEQUATE	0	0	--
HOT FORMING FACILITIES	4	0	0	--
	TOTAL COST		150,000	

*SPECIAL TOOLING REQ'D = $150,000

TABLE 3

ROCKET MOTOR CASE FABRICATION
FACILITIES REQUIREMENTS FOR 136 INCHES DIAMETER

FACILITIES	NO. AVAILABLE	ADDITIONAL REQ'D	FACILITY COST	LEAD TIME
VERTICAL LATHES	14	0	0	--
HEAT TREAT FACILITIES	1	0	0	--
EXPANDABLE MANDRELS	0	1	150,000	6 MO.
FORGED RING FACILITIES	ADEQUATE	0	0	--
ROLL FORMER	ADEQUATE	0	0	--
WELDING*	ADEQUATE	0	0	--
FLAT PLATE PRODUCTION	ADEQUATE	0	0	--
HOT FORMING FACILITIES	1	0	0	--
	TOTAL COST		150,000	

*SPECIAL TOOLING REQ'D = $150,000

TABLE 4

ROCKET MOTOR CASE FABRICATION
FACILITIES REQUIREMENTS FOR 156 INCHES DIAMETER

FACILITIES	NO. AVAILABLE	ADDITIONAL REQ'D	FACILITY COST	LEAD TIME
VERTICAL LATHES	14	0	0	--
HEAT TREAT FACILITIES	0	1	150,000**	3 MO.
EXPANDABLE MANDRELS	0	1	150,000	6 MO.
FORGED RING FACILITIES	ADEQUATE	0	0	--
ROLL FORMERS	ADEQUATE	0	0	--
WELDING*	ADEQUATE	0	0	--
FLAT PLATE PRODUCTION	ADEQUATE	0	0	--
HOT FORMING FACILITIES	1	0	0	--
	TOTAL COST		300,000	

* SPECIAL TOOLING REQ'D = $150,000

** MODIFICATION OF EXISTING FACILITY.

TABLE 5

ROCKET MOTOR CASE FABRICATION
FACILITIES REQUIREMENTS FOR 200 INCHES DIAMETER

FACILITIES	NO. AVAILABLE	ADDITIONAL REQ'D	FACILITY COST	LEAD TIME
VERTICAL LATHES	10	13	13,000,000	12-18 MO.
HEAT TREAT FACILITIES*	0	1	1,000,000	6-8 MO.
EXPANDABLE MANDRELS	0	1	300,000	3-6 MO.
FORGED RING FACILITY	ADEQUATE	0	0	--
ROLL FORMERS	ADEQUATE	0	0	--
WELDING	ADEQUATE*	0	0	--
FLAT PLATE PRODUCTION	ADEQUATE	0	0	--
HOT FORMING FACILITIES	NONE	1	150,000	6 MO.
	TOTAL COST		14,450,000	

*SPECIAL TOOLING REQ'D = $150,000

PART II

FABRICATION OF ROCKET MOTOR CLOSURES

FABRICATING TECHNIQUES CONSIDERED.

Spinning Technique.

Basically, two types of fabrication techniques utilizing spinning were considered for this study.

1. The first technique currently employed on the large segmented motor program and the most advanced to date is hot forming. Flat plate steel is rolled to shape over a mandrel at elevated temperatures. The rolling reduces the thickness of the steel by approximately 20 percent, but is controllable. Machining of the internal surface of the closure is not necessary, but grinding is required on the external surface. Joint ring forgings must be welded to the formed closure in a manner similar to that used in the case segments. Then, the entire assembly is heat treated, obtaining the desired stress level and sand blasted prior to final machining. The relatively unsophisticated equipment required for this method of fabrication (due to the small forces required to roll flat plate steel) make this method extremely attractive for large rocket motor closures.

2. The second spinning technique available is power shear spinning (see power shear spinning for case segment). A forged billet is utilized rather than a flat plate. The spinning forms the metal in cold conditions over a mandrel shaped to the internal dimensions of the finished closures. Heat treatment is also required. The joint ring can be formed as an integral part of the closure thus the need for welding an additional joint ring forging is eliminated. This spinning technique is ideally suited to forming surfaces of revolution (such as motor closures) but the large spinning equipment and special tooling required (due to the large forces required to shear steel forgings in the cold state) make this method less attractive for closures at the present time.

Welded Section Technique.

(Orange Peel Technique) This fabrication technique involves the welding of several stamped steel plates to form the finished closure. Expensive stamping dies are required to make the individual pieces prior to welding. These pieces then would require stress relieving prior to welding to relieve any stresses induced by the stamping operation.

This concept has been used mainly for smaller sizes to date. The large amount of welding, special welding fixtures, and radiographic inspection make this fabrication technique less attractive but not prohibitive. Furthermore, dimensional tolerances may dictate an expensive sizing operation after the large amount of welding. Similarly, a joint ring forging must be welded to the finished weldment, then the assembly must be heat treated prior to the final machining. Thus, because of economic consideration, this fabrication technique has been discounted for this study.

Explosive Forming Technique.

This concept is unique inasmuch as the closure is formed by an explosive force usually propagated by water. Flat steel plate is placed under water over a die of the desired shape. A shaped charge is detonated to provide the explosive force with water used as the medium to transfer the force to the steel plate. A costly die has to be fabricated for each closure size and tests must be conducted to ascertain size of charge required. Heat treating and machining of ends are required. There is considerable risk of breaking dies which make this method less attractive at the present time.

AVAILABLE FACILITIES.

Spinning Technique.

The following spinning facilities (starting with flat plate), are available.

1. Hot Forming.

It is believed that the largest hot forming capability for closures exists at Hanson Brothers, Inc., Whittier, Calif., and can form up to 160 inches in diameter with minor facility modification. The present facility requires specialized manual control to form the heads and is rather inefficient, but can do a satisfactory job. To date, eight 100-inch diameter closures have been successfully fabricated using the present facility. This existing facility can produce closures at a rate of one per week on a production schedule. Sixty days would be required to design and build all tooling required for any new motor diameters selected and this would be provided by the contractor.

A new hot forming facility with automatic control suitable for spinning heads up to 240 inches diameter can be constructed in six months for $150,000. This facility would permit an increased production rate and offer excellent reproducibility at a cost comparable to the manual operation.

The Phoenix Products Co., Phoenix, Ariz., has a hot forming capability of 144 inches in diameter. The tooling lead time is estimated to be 14 to 20 weeks and would cost about $50,000.

Spincraft, Milwaukee, Wis., is capable of hot forming dome closures up to 120 inches in diameter. They have estimated that $200,000 would enable a new machine to be build in 12 months to increase their capacity to any of the sizes considered.

General Electric, Cincinnati, Ohio, can hot form closures up to 100 inches in diameter.

2. Power Shear Spinning.

The same discussion presented earlier for fabricating case segments using the spinning techniques applies to motor closures. This technique is not presently developed for the larger diameters under consideration, and cannot be considered for use at the present time.

Welded Section Technique.

Many of the large fabricating companies would have the capability to tool up and produce closures by this method. After the special stamping and early welding operations, the final welding and machining operations parallel that required with the hot forming or explosive forming techniques.

Explosive Forming.

This method of fabrication has not been demonstrated in the sizes required. The leading companies that have done work in this field are: Aerojet-General Corp., Downey, Calif.; Allison, Indianapolis, Inc.; Rocketdyne, Canoga Park, Calif.; Ryan Aeronautical, San Diego, Calif. A 12 foot diameter, 1/8 inch thick closure was formed by Aerojet, Downey, Calif. All of the above companies state that it is entirely feasible to form large closures in this manner, but estimates are contradictory as to the tooling cost. The tooling costs estimated ranged from $40,000 to uncommital (high cost). It is believed that the dies used in explosive forming would be extremely costly with today's technology, and a single improper explosive charge detonation could cause extensive damage to the dies and may require replacement of the dies. Currently, more desirable materials and techniques are being developed to reduce die costs and improve the operation, after which time, this technique can be considered for production fabrication of large closures. However, at this time, explosive forming is still considered to be a high risk approach.

FACILITIES REQUIREMENT SUMMARY.

Two of the fabrication techniques considered for rocket motor closures, hydrospinning and explosive forming, are not considered desirable for a large motor program at the present time. The welded section technique does not require any special facilities in addition to those outlined under the roll and weld technique for case segments, but a large amount of special welding and forming tooling will be required for this technique. Table 6 summarizes the facility requirements for fabrication of rocket motor closures using the hot forming technique. It can be seen that facilities are not required for 100, 136, or 156 inch diameter closures. Even though there is only one hot forming machine of the size necessary, it is believed that it will be adequate to meet the program schedule. Opinions have been expressed by the leading machine builders that it is feasible to hot form 240 inch diameter closures.

TABLE 6.

ROCKET MOTOR CLOSURE FABRICATION FACILITIES REQUIRED

SPINNING (HOT FORMING) / DIAMETER (Inches)	HOT FORMING MACHINES			VERTICAL LATHES			FLAT PLATE PRODUCTION			HEAT TREAT FACILITIES	TOTAL FACILITY COST
	No. Available	No. Required	Cost For New Facility	No. Available	No. Required	Cost For New Facility	Max Width Available (Inches)	Max Width Req[3]	Cost For New Facility	COST	
100	4	1	None	15	2	None	180	132	None	None	None
136	1[1]	1	None	15[2]	2	None	180	149	None	None	None
156	1[1]	1	None	13[2]	2	None	180	169	None	None	None
200	1[1]	1	$150,000	8[2]	2	None	180	219	None[4]	None	$150,000

[1] Available in 4 Months if needed

Hanson Bro. Inc.
Whittier, Cal.

[2] Assume 14' Center Segment Length

[3] One Inch Skirt

[4] Can Weld Plates Together If Necessary

CONCLUSIONS

1. The roll and weld fabrication technique is the most desirable for all sizes of case segments considered. The machined forging technique (heat treatment after assembly) is considered acceptable as an alternate, but secondary, approach due to economic considerations.

2. The hot shear forming fabrication technique is the most desirable for all sizes of motor closures considered.

3. Sufficient quantities of Ladish D6aC or AMS 6434 (modified to AMS 255 or 256) steel are available in required form to support any of the programs presented.

4. Rail transportation is practical with 100, 136, and 156 inch diameter segments throughout continental United States. Movement of all 200 inch diameter segments is limited to water transportation

5. Segment length should be limited to sixteen feet if production schedules are to be met immediately with existing machining facilities.

6. Segment length can exceed sixteen feet only if costly, time consuming, coordinated effort is initiated to modify a large number of machining facilities throughout the United States.

7 Minimum facilities required (additional facilities would be desirable and enhance program as discussed in text) to meet production schedules are:

Diameter (Inches)	Facilities Required	Cost	Lead Time
100 and 136	Stretch Press	$ 150,000	3 - 6 mos
156	Stretch Press	150,000	3 - 6 mos
	Heat Treat (Modify)	150,000	3 mos
200	Machining	13,000,000	18 mos
	Heat Treat	1,000,000	6 - 12 mos
	Stretch Press	5,000,000	6 - 12 mos

RECOMMENDATIONS

For immediate state of the art production of large solid propellant rocket motors the following criteria should prevail:

1. Rocket motor case diameters should be limited to 160 inch maximum.
2. Segment lengths should be limited to 16 feet maximum.
3. Utilize the roll and weld fabrication technique for cylindrical segments.
4. Utilize the hot forming fabrication technique for closures.

APPENDIX I

CALCULATION FOR JOINT MACHINING TIME

(The 100 Inch Diameter Joint was used to scale up to the Larger Diameter Joint to predict Joint Machining Time.)

100 Inch Diameter Joint Forging

Cross Section Area (Fig. B)

Rough Forging: 6.38 $in.^2$

Final Shape : 3.62 $in.^2$

Area Change: 2.76 $in.^2$ = 43.2%

Total Volume of Finished Joint

$3.62\ in.^2 \times 100\pi = \underline{\underline{1140\ in.^3}}$

Volume Change

$2.76\ in.^2 \times 100\pi = 866\ in.^3$

160 Inch Diameter Joint Forging

Cross Section Area (Fig. A)

Final Shape: 12.79 $in.^2$

Total Volume of Finished Joint

$12.79\ in.^2 \times 160\pi = 6440\ in.^3$

Due to the basic simplicity of design for the 160 inch diameter joint, it is estimated that only 30% of the rough machined forging should be removed (instead of 43.2%).

Volume of Rough Forging

$6440 = .70\chi$

$\chi = 6440.70 = 9200\ in.^3$

APPENDIX I (Cont)

CALCULATION FOR JOINT MACHINING TIME

Volume Change

$9200 - 6440 = 2760$ in.^{3}

Net Increase in Material Removed

$2760/866 = 3.18$ times

100 Inch Diameter Takes 50 Hours to Machine Each Joint

Plus 24 Hours to Set Up Each Joint

For 160 Inch Diameter Rings Assuming 3.18Times

$3.18 \times 50 \times 2 \quad = 318$ Hrs

30 Hours x 2 = $\underline{60}$

378 Hrs Total Machine Time

380 Hrs = 2.25 wks/seg $\approx$ 2.5 wks/seg

4.3/2.5 = 1.7 seg/no/machine

= 5 Machines/3 Segments/Month

TOTAL VOLUME FINISHED JOINT = 6440 $IN.^3$

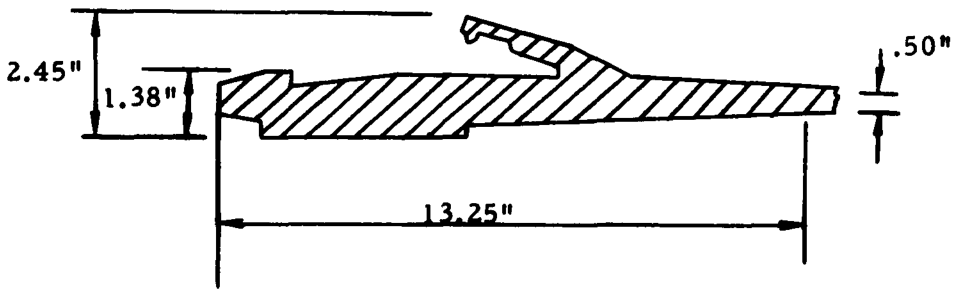

FIG. A 160 INCHES DIAGRAM SEGMENT JOINT
Approximate scale 1" = 4.0"

TOTAL VOLUME FINISHED JOINT = 1140

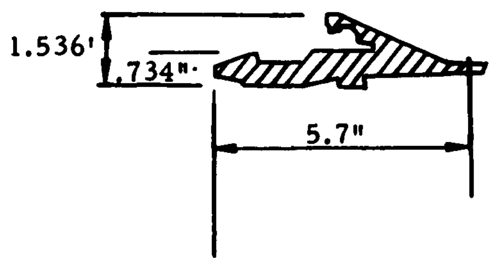

FIG. B 100 INCHES DIAGRAM SEGMENT JOINT
Approximate scale 1" = 4.0"

APPENDIX II

EXPANDABLE MANDRELS

Basically, there are two methods of fabricating expandable mandrels. The easiest facility to build is one that has a "short" mandrel of three or four feet in length. The case is expanded three or four feet at a time until the whole length of the case is expanded. The tolerance capability on the ends can be held to ±.005 inches, but the tolerances along the length of the case are only held to ±.030 inches.

The second method of fabrication is building the mandrel to the length of the case. The whole case is then expanded at one operation. The tolerances probably can be held to ±.005 throughout the case. However, the cost of the "long" facility is considerably more, and skepticism exists as to the feasibility of being able to fabricate such a facility for such large sizes. Cost estimates were as high as $500,000 and 12 months to fabricate.

It is believed that ±.030 inch tolerance along the case wall is adequate, and therefore, the facility cost estimate reflects the short mandrel facility cost.

APPENDIX III

LIST OF COMPANIES CONTACTED

Company and Location	Turning Facilities					Welding Facilities	Heat Treat Facilities				Size and Capacity of Roll Forms	Stretch Press Facilities
	Diam	Vert Clear	Toler	Cost and Time	Horiz Lathes		Type	Dimensions	Control Atmos Data	Quench		
John Mohr and Son Chicago, Ill.	26'	9.25'	±.008"	Impractical	None	26' Diam	Stress Relieve	16' Diam	No	No Info	16' Wide	None
Connelsville Mfg and Mine Supply Connelsville, Pa.	16'	5'10"	±.010"	No	No Info	No Info	----	--------	NONE	------	No Info	None
Blaw - Knox E. Chicago, Ind.	24' 12'	14' 10'	±.002 ±.002	Not Req'd	None	16' Diam All Types	Pit	20' Diam 16' Deep	No	Water Only	12' Wide Roll Formers	None
Cons. Western Steel Maywood, Calif.	16' 12'	8' 7'	±.002 ±.002	$100,000 for 14' Clearance	None	16' Diam All Types	Stress Relieve	17' Diam 35' Length			14' Wide	None
Verson All Steel Chicago, Ill.	20' 10'	12' 7.5'	±.002 ±.002	New and Will Not Modify	None	All Types	----	--------	NONE	------	None	Can Build Any Size (16') $500,000 - 7 Mo.
Hydraulic Press Mfg Mt. Gilead, Ohio	10'	7.2'	±.003	Will Not Modify	None	No Info	Stress Relieve	20' x 20'			No Info	
Hufford Machine Works El Segundo, Calif.	14' 12'	7.2' 7.2'		Cannot Cannot	None	No Info	----	--------	NONE	------	No Info	10' Dia x 23' Lg Can Build
Nooter Corporation St. Louis, Mo.	----	----	Not Inte	rested -----	----	All Types and Sizes	Car- bottom	12' Diam 53' Length	No	Water Spray	16' Wide	No Info
Nordberg Corp. St. Louis, Mo.	12' 20'	7' 12'	±.005	No Info	No Info	No Info	Stress Relieve	9'6" Wide 8'H and 22'Lg	No	None	12' Wide	None
Calmach El Monte, Calif.	27' 14'	25' 10'	±.005 Also Grind	Ready in Nov		None		Planning 166" Dia Gantry	Yes		None	None
Newport News Shipbldg Newport News, Va.	42' 16'	25.5' 16.9'	No Info ±.005		None	No Info		No Info			No Info	None
Giddings and Lewis Fon Du Lac, Wis.	20'	12'	±.002			No Info		None				No Info
Allis Chalmers Milwaukee, Wis.	16'	18'	±.005	Not Req'd	None	No Info	Pit	16' Diam 18' Deep	No	Oil Only	16' Wide	No Info
A. O. Smith Milwaukee, Wis.	20'	16'	±.005	Not Req'd	None	All Types	----	--------	None	-----	20' Wide	None

APPENDIX III (Cont)

LIST OF COMPANIES CONTACTED

Company and Location	Turning Facilities: Diam	Turning Facilities: Vert Clear	Turning Facilities: Toler	Turning Facilities: Cost and Time	Turning Facilities: Horiz Lathes	Welding Facilities	Heat Treat Facilities: Type	Heat Treat Facilities: Dimensions	Heat Treat Facilities: Control Atmos Data	Heat Treat Facilities: Quench	Size and Capacity of Roll Forms	Stretch Press Facilities
Leo Kinco Montebello, Calif.	12'	12'	±.010		7' Dia 12' Lg	None	----	--------	None	-------	No Info	None
Nat'l Steel Supply Los Angeles, Calif.	14'	7'	±.00-1/2	Cannot	60"Dia	None	----	--------	No Info	-------	Rolling Equip. Available	None
Todd Shipyards San Pedro, Calif.	None				10'Dia 30'Lg ±.005	All Types	No Info	10'x10'30'	No		20' Wide Rolling Eq Avail	None
C. H. Wheeler Philadelphia, Pa.	19' 24'	12' 12'	±.003 ±.003		None	Available	----	--------	None	-------	No Info	None
Treadwell Const. Midland, Pa.	30'	12'	±.0001		None	No Info	----	--------	No Info	-------	No Info	No Info
Manitowoc Engr. Corp. Manitowoc, Wis.	14' 25'	10' 15'	±.005 ±.--[illegible]	Can modify		Equipment Available	----	--------	None	-------	Equip Available	None
United Heat Treat Fort Worth, Tex.	---	---	--No Info	-------	----	No Info	Slot and Car	14' 7-1/2" H 16' Wide 8' Long	Yes	Any	No Info	No Info
BLH Ind Eqp Div Eddystone, Pa.	40' 35'	16' 20'	±.008 ±.008	Will Build			----	--------	None	-------	12'Wide	None
J. W. Rex Landsdale, Pa.	---	---	No Info	-------	----	No Info	Gantry	140" Diam	Yes	Water	No Info	No Info
Wm. B. Pollack Youngstown, Ohio	22'	11'	±.005	-------	No Info ---	No Info	----	-------	No Info	-------	No Info	No Info
Westinghouse Corp. Sunnyvale, Calif.	16'8"	25'	±.005	-------	No Info ---	No Info	----	-------	No Info	-------	No Info	No Info
Kaiser Fleetwing, Inc. Bristol, Pa.	None	None	None	Can modify to 168" dia at $100,000/ machine	2-108" dia-24' long	No Info	----	-------	None	-------	No Info	No Info
Naval Ship Yard Seattle, Wash.	22' 14' 12'	11' 7' 7'	±.005 ±.005 ±.005	Can modify at Reasonable Cost for Vert	No Info	No Info	----	-------	No Info	-------	No Info	No Info

APPENDIX III (Cont)

LIST OF COMPANIES CONTACTED

Company and Location	Turning Facilities					Welding Facilities	Heat Treat Facilities				Size and Capacity of Roll Forms	Stretch Press Facilities
	Diam	Vert Clear	Toler	Cost and Time	Horiz Lathes		Type	Dimensions	Control Atmos Data	Quench		
Portland Indus. Portland, Maine	12' 16' 16' 24' 33'	10' 9-1/2' 9-1/2' 9' 10'		Can Modify Easily with Blocks for Vert. Clear.	No Info	No Info	----	--------No Info	------	------	No Info	No Info
Stearns Rogers Denver, Colo.	16' 13'1"	10'7" 12'4"	±.005 ±.005		No Info	No Info	----	--------No Info	------	------	No Info	No Info
Kaiser Steel Napa, Calif.	12'	6'		Can be Mod. for Higher Vert. Clear	18'Dia 48'Lg ±.015	No Info	----	--------No Info	------	------	No Info	No Info
U. S. Steel	---	---	---	None	---	No Info	----	--------No Info	------	------	No Info	No Info
Bethlehem Steel Bethlehem, Pa.	25'	160"	±.008		No Info	Large Facility	----	--------No Info	------	------	No Info	No Info
Babcok and Wilcox Barberton, Ohio	16'	18'	±.008		19'Dia		----	No Info ---	No	No Info	10'Wide Roll Formers	No Info
Erie Forge and Steel Erie, Pa.	15' 25'	10' 12'		Install Nov 1	106"	No Info	----	--------No Info	------	------	No Info	No Info
Excelco Development Silver Creek, N. Y.	10' 10' 13'-4"	13' 13' 16-18'	--- --- ---	Can Modify with Blocks	3-160" Dia by 24' Lg	Large Facility	----	None --------	--------	------	No Info	No Info
General Electric Schenectady, N. Y. and Cincinatti, Ohio	Large	Facility No Details	---	----Large Facility-- No Details		-----	Gantry	120"Dia	Yes	Yes	Large	No Info

APPENDIX III (Cont)

LIST OF COMPANIES CONTACTED

COMPANY	CAPABILITY	SIZE	REMARKS
Arrow Smith Tool and Die Co. Inglewood, Calif.	Expandable mandrels facility	13' Dia, 12' Long 1200 Ton	$150,000 3 mo lead time for new machine
Bullard Co.	Fabricates vertical lathes	14' Vert. Clearance 14' Dia	$400,000 18 mo lead time
		14' Vert Clearance 13' Dia	No estimate 14 mo lead time
Curtis Wright	Hydrospinning capability	65 Inch Dia 80 Inch Long	$400,000 to build new machine takes 17' Dia
Lukins Steel	Manufacture flat plate	Up to 170" Width	
Arde-Portland	Cryogenic stretch forming press for case fabrication		$250,000 for new facility
Phoenix Products Co. Milwaukee, Wis.	Hot forming facility for closures	12' Max Dia	$50,000 tool 14-20 weeks lead time
General Electric Co. Cincinatti, Ohio	Hot forming closure facility	100" Max Dia	
General Electric Co. Schenectady, N. Y.	Explosive forming capability	No Info on Size	
The Boeing Co. Wichita, Kan.	Flat Plate rolling machine	Up to 36' Wide	
The Marquardt Corp Los Angeles, Calif.	Spinning capability for head closures	Max 63" Dia	
Grotness Machine Works	Fabricates stretch processes	14' Dia 20' Long	$300,000 8-12 mo lead time
Douglas Aircraft Corp Santa Monica, Calif.	Expandable mandrel	6' Dia 30' Long	Used for Minuteman cases

APPENDIX III (Cont)

LIST OF COMPANIES CONTACTED

COMPANY	CAPABILITY	SIZE	REMARKS
Ryan Aeronautical San Diego, Calif.	Explosive forming capability	Claim 20' Dia. Capab.	Require 3-4 mos for tooling
Rocketdyne Canoga Park, Calif.	Explosive forming	--	Est. $40,000 tooling per die.
Aerojet-General Downey, Calif.	Heat Treat facility Explosive forming	100" Dia-Gantry, Atmospheric Controlled 12' Dia. - 1/8 In Thick	Non-committal on tooling costs
Allison Corp. Indianapolis, Ind.	Explosive forming	--	Experimental stage
Spincraft Corp. Milwaukee, Wis.	Hot forming capability	10' Dia. Max.	$200,000 - 12 mos lead time for 200" dia. machine
Hufford Corp. El Segundo, Ca'if.	Hydrospinning capability for cases	120" Dia. Max.	160" dia. machine costing $2,500,000 - 12 mos. lead time
Hanson Brothers Whittier, Calif.	Hot forming capability	160" Dia. Max.	$150,000 - 6 mos. lead time for new 200" dia. machine
U.S. Steel Los Angeles Sales Office Los Angeles, Calif.	Flat plate production - Forged rings	147" Wide - 40' Long 17' Dia.	Seven - eight wks lead time 10 wks lead time - 1 per wk.
Stearns Rogers Co. Denver, Colo.	Horizontal lathe capability	26' Dia. - 36' Long. 14' Dia. - 33' Long.	--
Solar Aircraft Corp. San Diego, Calif.	Heat treat facility (Pit)	10' Dia. - 21' Deep.	Not practical to modify. No atmospheric control. No quench facility.
Nat'l Steel Supply Co. Los Angeles, Calif.	Heat treat facility (Pit)	16' Dia. - 25' Long. 8' High.	Willing to modify to larger height
Douglas Aircraft Corp. Santa Monica, Calif.	Heat treat facility (gantry)	Max. Dia. 6'2" 18' Long	Atmospheric control - Oil and water quench.
Thurner Co. Milwaukee, Wis.	Heat treat facility	None	Negotiating to build 100" dia. gantry furnace. Atmospheric control - Salt and water quench. Willing to modify to larger size.
Pittsburgh Metal Processing Co. Pittsburgh, Pa.	Heat treat facility. Car bottom.	--	Not usable.
Boeing Aircraft Co. Seattle, Wash.	Heat treat facility	5' Dia. - 13' Long	Not usable

APPENDIX III (Cont)

LIST OF COMPANIES CONTACTED

COMPANY	CAPABILITY	SIZE	REMARKS
Cal Doran Co. Los Angeles, Calif.	Heat treat facility	12' Dia. - 14' Long Max. Temp. 1250°F	Willing to fabricate 160" dia. furnace (gantry) - 20' long - atmospheric control - water quench - $700,000 and seven months lead tir .
Lakeside Steel Improvement Co. Cleveland, Ohio	Heat treat facility	--	Too small
Bethlehem Steel Co. Bethlehem, Pa.	Forged rings	14' Diameter.	--
Kaiser Steel Co. Napa, Calif.	Forged rings	16'8" Dia.	--
Baker and Perkins Saginaw, Mich.	Roll formers	36' Wide	--
Cameron Iron Works Houston, Tex.	Forged rings	5' Dia. Max.	--

DISTRIBUTION LIST

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SSD (SSRTR)	2
USAF (AFMPP-PD-2)	2
AFFTC (FTOOT)	10
ASTIA	10
6593 T.G. (D) (DGSMA)	300
6593d Test Gp (DGLP)	5